High fidelity reconstruction of the ancient Egyptian temple of Kalabsha

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High Fidelity Reconstruction of the Ancient Egyptian Temple of Kalabsha

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ABSTRACT
The ancient Egyptian temple of Kalabsha dates back to 30 BC. In 1963 the temple was dismantled and moved to a new site in order to save it from the rising waters of the Lake Nasser. Computer graphics in collaboration with Egyptologists makes it possible to recreate the temple on a computer, place it back to its original location and orientation, and illuminate it, as it may have appeared some 2000 years ago. Accuracy is of the highest importance in such archaeological reconstructions when investigating how a site might have appeared in the past. Failure to use the highest fidelity means there is a very real danger of misrepresenting the past.

This paper describes the practical methodology that should be undertaken in order to create a high fidelity reconstruction and realistic lighting simulation of an ancient Egyptian temple.

Categories and Subject Descriptors
I.3.7 [**Computer Graphics**]: Three-Dimensional Graphics and Realism—*Animation, color, shading, shadowing and texture, virtual reality.*

Keywords
High fidelity graphics, virtual archaeology, ancient Egypt.

1. INTRODUCTION
Computers have long been used by archaeologists for tasks such as recording excavation plans, illustrating artefacts and presenting the results of scientific analyses. Lately computer generated images have become commonplace in television documentaries, film and the publishing industries as a part of presenting ancient cultures [15]. In addition to merely presenting information, recent advances in computer graphics, such as low cost, high performance hardware, tools for efficiently handling data sets from laser scanners [3], etc., should now enable virtual archaeology to become a valuable tool to assist archaeologists in their interpretation of the past. However, if we are to avoid misleading representations of how a site may have appeared, then the computer generated environments should not only look real, they must simulate very accurately all the physical evidence from the site [4, 23]. In this paper we describe the key practical considerations which should be taken into account when undertaking a reconstruction of a heritage site with a view to investigating how it may have appeared in the past. The issues include: constructing an accurate geometric model, providing detailed surface materials and textures, determining the spectral properties of the ancient lighting materials, creating a light model for flame, and, rendering the model with physically correct lighting. The novelty of this work is the emphasis we place on the high fidelity that must be achieved at each and every stage of the reconstruction process to ensure a meaningful result which can be used by the archaeologists, rather than merely a pretty picture. The site we consider is the ancient Egyptian temple of Kalabsha, figure 1.

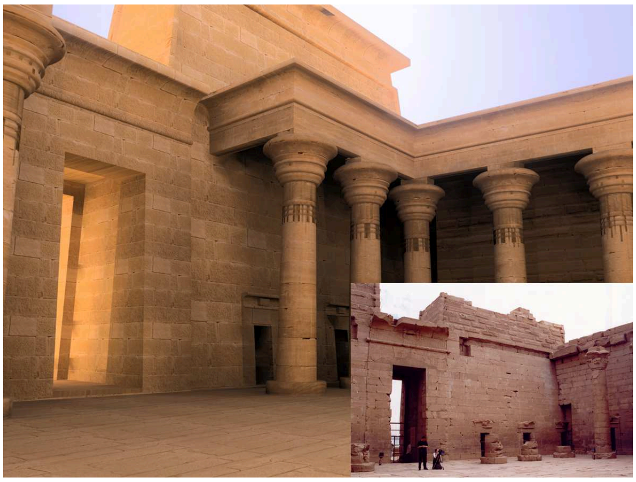

Figure 1: Computer reconstruction and a view of Kalabsha as it appears today.

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2. BACKGROUND

Over the past decades, archaeologists have been quick to adopt the techniques of computer visualisation as a means of presenting and analysing their data. Although not completely replacing the traditional three-dimensional drawings, from the late 1980s computer aided drawing techniques became increasingly popular as a means of virtually reconstructing archaeological sites [13, 27, 28].

In recent times, the popularity of virtual archaeology has led to a significant number of virtual reconstructions ranging from non-photorealistic presentations, Quicktime VR images, realistic looking computer models, augmented reality applications and even full reconstructed urban environments, for example [1, 9, 10, 30, 36, 37]. There are now conference series which annually contain a number of papers in this field, including Computer Application in Archaeology [14] and VAST (which incorporates the Eurographics Symposia on Graphics and Virtual Heritage) [17]. Despite the popularity of virtual archaeology, there are very few high fidelity reconstructions that attempt to authentically represent how a site may have been perceived in the past. Crucial to this accurate perception is the need to correctly model the ancient lighting [8, 29].

The numerous archaeological sites in Egypt has made it a popular topic for virtual archaeology. For example, a reconstruction of the pyramids at Giza was done in 1991 [21] and in 1994 a virtual reality reconstruction for the SGI Onyx2 platform was made of the Tomb of Queen Nefertari for the exhibition Nefertari, luce d'Egitto [18]. An interactive reconstruction was produced in 1994 by Riesman at Learning Sites Inc. of the Fortress of Buhen [19] and Shiode and Grajetzki constructed a series of low-end, 3D models that are navigable though the Web for visualisation and exploration using VRML. They focused mainly on the Hawara Labyrinth site [33]. Digital Egypt for Universities (DEU) is a collaboration between Centre for Advanced Spatial Analysis (CASA) and the Petrie Museum of Egyptian Archaeology, which also have made a series of 3D reconstructions in VRML format for exploration of different hypotheses in ancient Egypt [16]. Most recently, Cain et al. have been working on using laser scanners to capture and subsequently reconstruct a number of key objects, such as the Colossus of Ramesses II [2].

3. THE TEMPLE OF KALABSHA

The temple of Kalabsha is the largest free-standing temple of Lower Egyptian Nubia located about 50 km south of Aswan and built of sandstone masonry. The temple dates back to the Roman Emperor Octavius Augustus, 30 BC, but the colony of Talmis evidently dates back to at least the reign of Amenhotep II in 1427 - 1400 BC [32]. The temple was dedicated to the Nubian fertility and solar deity known as Mandulis and the walls are covered with text and inscriptions depicting Egyptian deities such as Isis and Osiris. The temple itself was never finished.

The design of the temple is classical for the Ptolemaic period, figure 2, with pylon (4), courtyard (1), hypostyle hall and a three-room sanctuary. In this case the Pylon is offset, which creates a trapezoid in the courtyard beyond. The courtyard just inside the pylon once had columns on three sides. At either end is a staircase that leads to the upper stories of the pylon. The gateway of the temple is 9.70 meters high, on top of which there are inscriptions of the disk of the sun as well as scenes of the king giving sacrifices and praying. The small rooms in the surrounding wall were used for storage. After the hypostyle hall (2) are the three chambers, the pronaos (5), the naos (6), or sanctuary where statues of gods were located, and the adyton (7), which is the innermost or secret shrine [12, 20]. There is also a nilometer (3), which was used to collect sacred water for the gods. Two further elements of religious importance remain outside the enclosure wall, which is in turn narrowly enclosed by another (outer) enclosure wall. At the South West angle of this latter enclosure is the Mamisi where the sacred birth of the Pharaoh is venerated. Finally one complete element of the earlier temple is preserved, the so-called Ptolemaic Chapel. The first enclosure wall is meant to bind an area of 66.08m x 33.04m. The original overall height of the Pylon was probably 16.25m [6, 38].

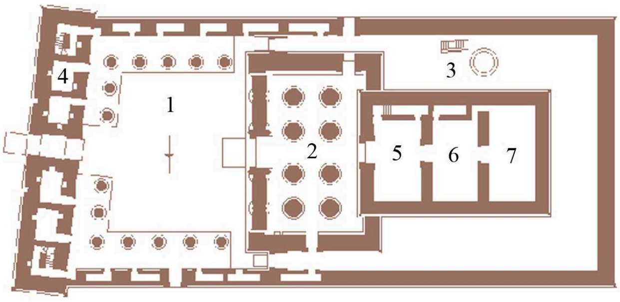

Figure 2: Plan view of Kalabsha [12].

3.1 Old location

The temple was originally built at Kalabsha (Talmis) but with the construction of the Aswan High Dam in 1959, it became apparent that the temple would disappear under the waters of the Nile by June 1962. In order to save this and the many other monuments threatened by the rising waters of the dam, Egypt sought the help of the United Nations Education, Scientific and Cultural Organisation (UNESCO). In 1959 UNESCO took the first major step of calling together a group of leading authorities in various fields of archaeology and architecture to make recommendations. To encourage

Figure 3: Dismantling the temple [34].

Figure 4: Current location of the temple of Kalabsha.

collaboration, and with time running out, Egypt's then culture minister announced that his government would cede to the foreign archaeological teams half of all finds made during excavations, other than those considered unique or essential to Egypt's national collections. Moreover, any country, which sent an archaeological expedition to Nubia, would be given a concession to dig in Egypt itself. Egypt would also allow the transfer abroad of certain Nubian temples and various antiquities from the state reserves.

Dismantling of the temple of Kalabsha began in 1963, when it was already partially under water, figure 3. The various units of masonry were each identified with a number, and their position shown on a measured drawing. The blocks were then broken from the bond and removed from the wall. Some 13,000 blocks, and in total 20,000 tons of stone were dismantled and stored until 1970, when the temple was reassembled at its present location at New Kalabsha (Chellal). The temple now stands 750m to the south of the Aswan High Dam, figure 4.

4. RECONSTRUCTING THE TEMPLE

A highly detailed geometric model is the first step in the virtual reconstruction process. Without the appropriate authorisation it is not possible to undertake a three-dimensional laser scan of the temple. Typically it can take many months even years to acquire such permission. Fortunately, when the temple was dismantled in 1963, it was very well documented, including detailed drawings and measurements, so that it could subsequentially be physically reconstructed [34, 38]. The detailed top, front and side views were used on images planes in Alias Maya and together with the measurements, it was possible to achieve a detailed geometrical model, figure 5.

Equally important to the geometric model, is the representation of the materials, which determines how the light interacts with the geometry. The materials of the temple are predominantly diffuse, so it was not necessary to accurately determine their precise Bidirectional Reflectance- Transmittance Distribution Function (BRTDF) using samples and a sophisticated device such as a gonioreflectometer. The materials were modelled directly in Radiance without any

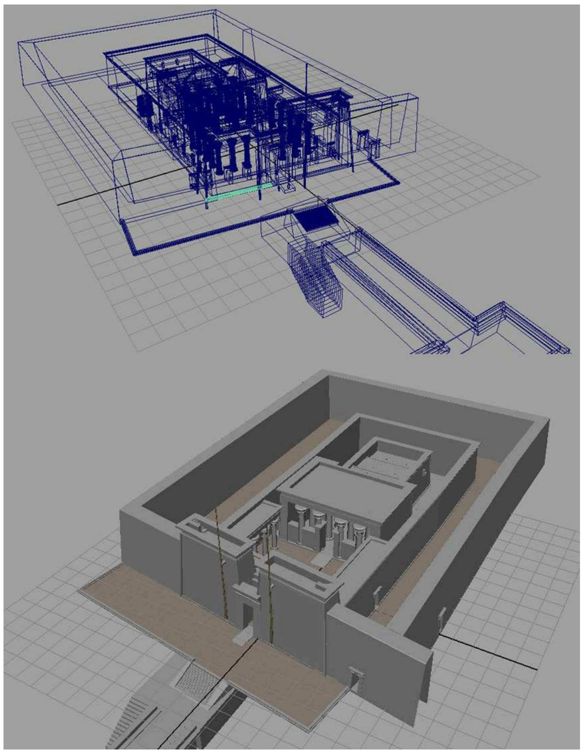

Figure 5: (a) Wireframe (b) flat shaded model.

significant loss of accuracy [22].

4.1 Illumination neutral textures

Our goal was to relight the temple using the lighting prevalent in ancient Egypt. Since all photographs taken for the textures of the temple would also contain the illumination in which the pictures were taken, in order to acquire illumination neutral textures, a piece of green card was introduced. The diffuse nature of the materials allowed us to take TIF photographs, without moving the camera, of materials with and without a piece of green card in the scene, as shown in figure 6.

The spectral properties of the card under a known light source were determined previously using a Spectrophotometer, eq. (1). The illumination at each pixel of the texture photograph could now be corrected based on the equivalent pixel value of the green card photograph. In total 21 different seamless textures were used for the outdoor environment with the largest resolution being 2188×945 which was also repeated for larger areas.

An alternative technique to the green card would have been to use a Macbeth Color chart and the program, *macbethcal* in Radiance to directly compute the correct color and brightness. Neither of these techniques is perfect and will not work in the presence of highly specular or complex geometrical surfaces, however, for the diffuse surfaces of the temple, it enabled us to acquire a good approximation of illumination neutral textures which we could subsequently relight in our reconstruction.

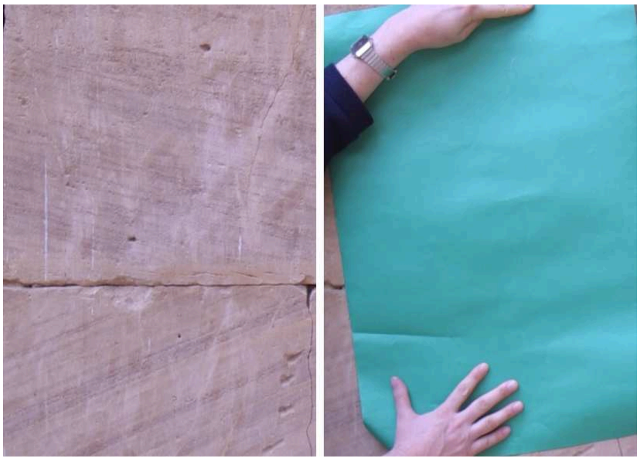

Figure 6: Texture (a) without and (b) with green card.

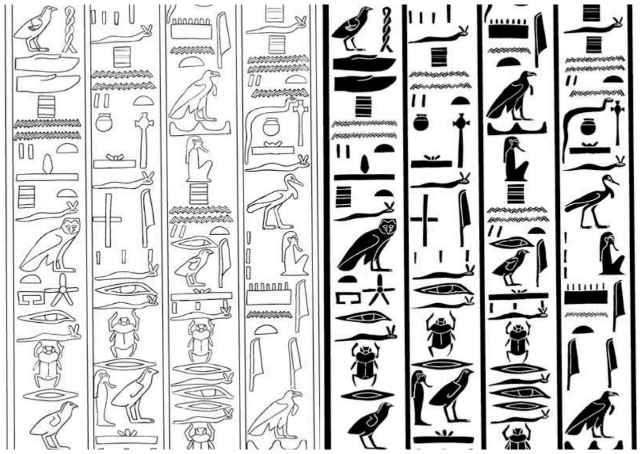

Figure 7: (a) Iconographic documentation and (b) corresponding height map.

4.2 Modelling the hieroglyphics

One of the questions that the Egyptologists were keen to investigate was whether the three-dimensional nature of hieroglyphics contributed significantly to the perception of them when viewed under flickering flame light, as they would have been viewed in the past. Standard texture mapping is thus not sufficient to incorporate the hieroglyphics in the model. As laser scanning was not available, results from the Egyptologists traditional iconographic documentation, or epigraphy, technique were used [7]. The most common method used for making facsimiles in Egypt today is to make a full-size original on the wall, with all the necessary features and details. The copy is made on transparent flexible plastic acetate film in sheet or roll form with a permanent marker pen of various thickness. This image is then copied onto tracing paper or film, depending on the epigrapher. Another approach is to trace from high resolution photographs, one example is shown in figure 7(a).

To create the three-dimensional surface, a height map for the hieroglyphics was created by first inverting the iconographic documentation image, figure 7(a). The black areas outside the hieroglyphics were then selected and deleted. The inside was also selected and deleted if the hieroglyph contained a hole, such as the black area between the legs of the bird of figure 7(b). Gaussian blur was used on the inverted image to eliminate sharp edges. Gaussian noise was added before blurring the image. This makes the surface look more natural, since the carvings have a rough surface where they were carved.

Mayas Sculpt Surfaces Tool was then used to convert the height map into a deformed three-dimensional polygon surface. In order to get sufficient precision 500,000 triangles were used for one patch ($0.5m^2$). This method can be used for hieroglyphics for which the carvings go into a surface and for those that stand out from the surface. A laser scanned area of the same size at a distance of 100 cm would have about 300,000 triangles.

Hieroglyphics in ancient Egypt would have been brightly coloured rather than devoid of colour as they are typically seen today. In most temples the colour has long since faded as the energy of the solar light has destroyed the chemical and physical structure of the organic material that held the mineral pigments on the walls. In the temple of Kalabsha some colour also disappeared when it was under water. Fortunately, there are still magnificent examples of how the temples were coloured in some tombs and temples, and in this project spectrophotometer readings from other sites of the same period were used to recolour the virtual hieroglyphics.

4.3 Rendering

Radiance was selected as the rendering system as it accurately simulates how light would propagate within an environment [22]. It is capable of computing lighting simulations for both day lighting and flame-lit environments which are perceptually indistinguishable from a real scene [24, 29].

4.3.1 Daylight

The sun was a key feature of ancient Egyptian religion and thus the position and orientation of the temple would have been carefully chosen. Knowing the co-ordinates of the original location allows us to place the computer model back to where it was originally built and make a sun simulation to study how the light shines on the temple during a day.

Daylight data is a feature of Radiance, derived from the Commission Internationale de l'Eclairage (CIE) standards [22]. The Radiance program gensky produces a Radiance scene description for the CIE standard sky distribution at the given date and local standard time. This command allows the month, day, time, latitude, longitude and meridian to be

	Old location	New location
LAT (DMS):	23 33' 0N	24 4' 60N
Lon (DMS):	32 52' 0E	32 52' 60E
Altitude:	172m	141m

Table 1: Position coordinates for the Kalabsha Temple.

specified to see how the temple is lit during a specific time of the day. Other sky models could also have been used [26, 25].

4.3.2 Interior lighting

Torches or tapers are known from representations on the walls of New Kingdom tombs and temples, as well as from actual examples among Tutankhamen's burial equipment. The most common type was made of a strip of linen folded double at half its length and twisted, then soaked in fat. Vegetable oils such as olive- and sesame oil were used as fuel for lamps, as well as animal fat and other oils that are less easily identified. The most frequently used lamp was a dish of oil of fat with a serpentine-floating wick [11]. The lamps inside the temple were modelled from examples in the Cairo museum.

High fidelity lighting is crucial for an accurate reconstruction of any archaeological site [8], and thus detailed spectral data of the various oil flames was gathered using a Spectroradiometer, which allows the absolute value of the spectral characteristics to be measured without making physical contact with the flame. This device can measure the emission spectrum of a light source from 380nm to 760nm, in 5 or 10nm wavelength increments, giving an accurate breakdown of the emission lines generated by the combustion of a particular fuel. The spectral values for each of the oils are different from each other and of course very different from the spectral values of modern lighting [8].

The measurements were performed in a completely dark room and the device was aimed at a board coated with a 99 % optically pure Eastman Kodak Standard white powder, which diffusely reflects the aggregate incident light. The spectral data for organic olive oil is shown in figure 8, with the spectral radiance as the y-axis and the wavelength the x-axis. The spectral data was converted into RGB values for use in Radiance, using the CIE 1931 standard.

In order to simulate the sunlight entering the inner chambers through the window holes in the walls, the *mkillum* program was used to compute the light source distributions for each surface, replacing them with secondary sources whose contributions can be computed more efficiently. This program makes *Radiance* aware that the openings are the effective sources, taking into account the outdoor geometry, and they will always be sampled by direct rays [22, 31].

$$\begin{array}{c} X = 14.39 \qquad Y = 19.49 \qquad Z = 6.03 \\ \begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 3.240479 & -1.537150 & -0.498535 \\ -0.969256 & 1.875992 & 0.041556 \\ 0.055648 & -0.204043 & 1.057311 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \\ R = 13.67 \qquad G = 22.87 \qquad B = 3.20 \end{array} \tag{1}$$

5. RESULTS

The methodology followed ensures that all the available evidence has been incorporated into our model and thus we can be confident of achieving high fidelity results.

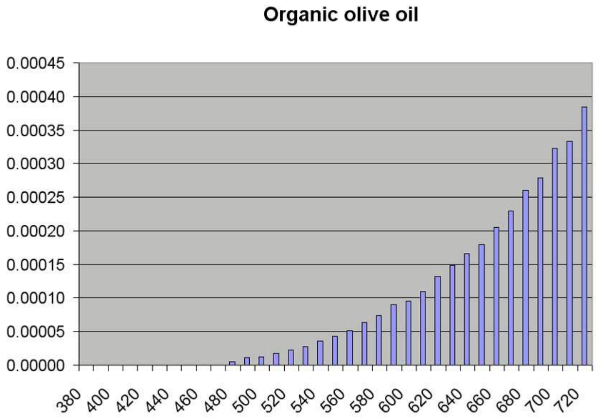

Figure 8: Spectrum of organic olive oil.

One important aspect of a computer reconstruction is that it enables the archaeologists to virtually replace parts of a site which have disappeared over time. Figure 9(a) shows the courtyard as it appears today and (b) how it may have appeared in the past with all the columns intact.

Figure 10(a) shows coloured hieroglyphics illuminated under modern lighting, and (b) lit by a sesame oil lamp. Note how blue, which is clearly blue in the modern light, is almost perceived as green when lit by a sesame oil lamp. Many archaeological sites today are illuminated by electric lighting and strictly controlled and it is not possible to visit the site and investigate in reality the perception of the hieroglyphics under flame light as they would have been perceived in 30BC. By using virtual reality techniques this is now feasible.

The sun was an important feature of Egyptian religion. Even if the temple was in its original location it would not be possible to go to the site and investigate how sunlight may have influenced the perception of the temple in the past because, as figure 9 shows, the temple has been damaged over time, and the missing parts of the temple may well have significantly affected the overall perception of the site. Once the

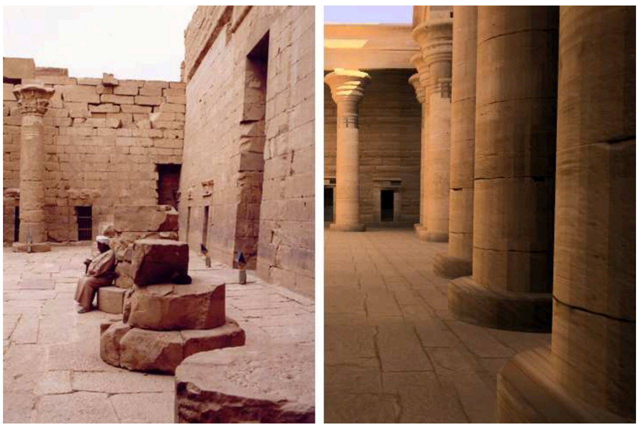

Figure 9: (a) View of the courtyard today and (b) how it may have appeared in 30BC.

Figure 10: Reconstructed hieroglyphics lit by (a) modern lighting and (b) a sesame oil lamp.

detailed model exists, including the "virtual repair" of the site, it is possible to create animations showing how sunlight would have affected the perception of the temple over a period of time. These animations can be validated with real video recordings taken on site, by positioning the model at the new location and orientation and setting the year in the sun simulation to 2003 [35]. Figure 11 shows the temple at 9am on 21 January 2003, and how the temple may have appeared at 9am on 21 January 30 BC.

6. DISCUSSION AND FUTURE WORK

This paper has described the practical considerations that should be heeded when creating a virtual reconstruction of a cultural heritage site, in our case the ancient Egyptian temple of Kalabsha. If such a reconstruction is to be used as a tool to investigate the past, then it is crucial that it incorporates all existing evidence of the original structure. Having created the detailed model, modern physically based high fidelity graphics techniques can produce meaningful images and animations for the archaeologists.

In addition, working with archaeologists has shown us that the focus and purpose of every reconstruction must be built on the questions the archaeologists want to answer. In this example, they were asking about the visual perception of a site illuminated with the lighting prevalent in ancient Egypt. This required measurement of the appropriate lighting materials, a detailed model including full geometry for the hieroglyphics and an accurate lighting visualisation of both daylight in 30BC and flame lighting. A significant advantage of such a high fidelity reconstruction is that it enables the Egyptologists to experiment with different hypotheses concerning the artificial lighting present in the interior of the temple and how this would have affected site utilisation.

The positioning of the lamps cannot be supported in any evidence found by Egyptologists, but with help of reconstructed lamps with olive- and sesame oil it is possible to explore how the ancient lighting may have been positioned to achieve maximum lighting with a minimum number of lamps positioned so they would not get in the way of any activities within the environment. Sun simulations together with an accurate model of the temple also make it possible to see how far the sunlight would have reached into the temple and whether the few available holes were positioned in order to light something special at certain times of the year.

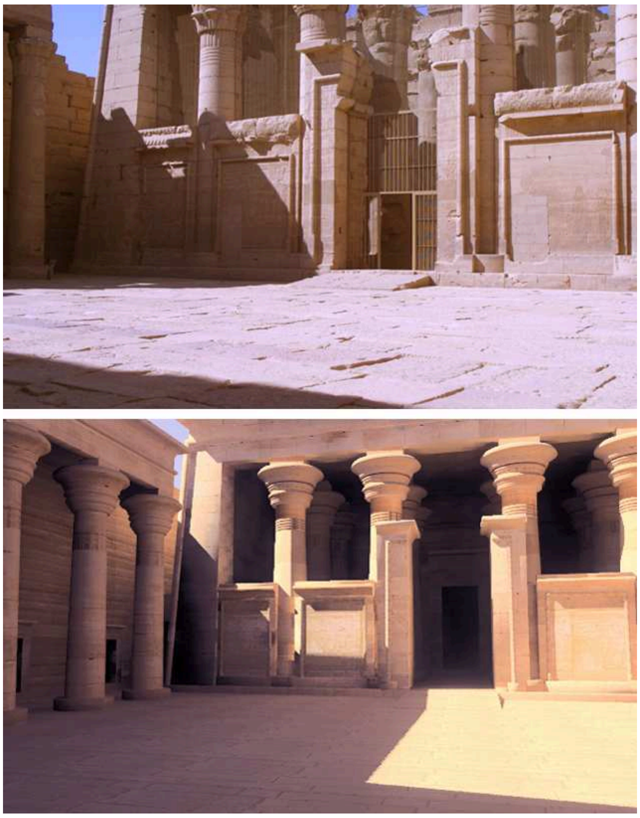

Figure 11: Kalabsha (a) 9am, 21 January 2003 (b) 9am, 21 January 30BC.

The static image, figure 10, shows that the perception of the hieroglyphics is significantly different under flame light and shadows do enhance the three-dimensional structure of the carvings. Future work will incorporate a flickering flame model, such as presented in [5], to investigate just how the perception of the hieroglyphics would alter under such lighting conditions. Further work also needs to be done in order to simulate hieroglyphics paint since simple spectrophotometer measurements may not suffice to recreate the correct reflectance behavior of these materials. Estimating them as predominantly diffuse as for the rest of the temple might not be accurate enough. In order to improve the model further laser scanning is required for more complex parts, such as the top of the pillars, even though the resulting data set for the whole model would be complex to work with on a single computer.

It is also important to consider how we display the resulting images. Earlier attempts has used tone mapping operators (TMOs) to reproduce visibility and the overall impression of brightness, contrast and colour of reality onto the limited dynamic display of modern CRTs. By using high dynamic range (HDR) computer monitors that are capable of producing screen luminances and contrasts comparable to those in a real space we can simulate our virtual environments more accurately. We will never know for certain how the temple of Kalabsha was used or exactly what the lighting was, but a high fidelity graphics reconstruction can show what was possible.

7. ACKNOWLEDGMENTS

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